

CYPR-CD00230

UNITED STATES PATENT APPLICATION

FOR

A METHOD FOR EFFICIENT SUPPLY OF POWER TO A
MICROCONTROLLER

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FILED IN 62-23650

A METHOD FOR EFFICIENT SUPPLY OF POWER TO A
MICROCONTROLLER

RELATED U.S. APPLICATION

5 This application claims priority to the copending
provisional patent application, Serial Number 60/243,798,
Attorney Docket Number CYPR-CD00167, entitled "Advanced
Programmable Microcontroller Device," with filing date
October 26, 2000, and assigned to the assignee of the
10 application.

FIELD OF INVENTION

15 The present invention relates to the field of power
supplies for integrated circuits. More specifically an
embodiment of the present invention relates to a power
supply pump circuits used to power microcontrollers.

BACKGROUND OF THE INVENTION

20 A controller is generally a device used to control
other processes or external devices. A microcontroller is
an electronic device, a highly integrated chip, which
performs controlling functions. A microcontroller includes
all or most of the parts needed for implementing a
controller but physically, is a smaller device (e.g., and
25 integrated circuit). The demands for reduction in the size

of microcontrollers, due to the nature of their use, have led to the miniaturization of the electronic components constituting a microcontroller. The reduction in the physical size of microcontrollers has caused an increase in the scope of their use across different fields. The spectrum of the application of microcontrollers varies across different and diverse disciplines. For example, microcontrollers are being used in the field of medicine, for example a pacemaker monitoring a patient's heart beats, or in the field of meteorology, where a microcontroller is installed in a very remote location to periodically record, log and report atmospheric conditions. In many instances more than one microcontroller is found in a single device to perform a certain function. In today's technology, almost all electrical and electro-mechanical devices use microcontrollers for the purpose of controlling or monitoring different processes.

Microcontrollers require a source of power for their operation. Most microcontrollers only support 4.5 to 5 volts operations and thus require a power source capable of supplying that amount of power. Dry cell batteries are typically used to support a microcontroller's power demand.

To meet such power requirements, generally 2-3 dry cells (e.g., type AAA) power the microcontrollers. Comparing the size of electronic components used in a typical microcontroller and the batteries used to power the device, the batteries are the most voluminous component in a microcontroller. With the ever increasing demand for reduction in the size of microcontrollers, a need exist to reduce the size of the power supply providing power to the microcontrollers.

Effort should be made to conserve energy during all modes of operation. A typical microcontroller does not operate on a continuous basis, the device is generally programmed to operate based on the demand or in accordance with a programmed schedule. Once the microcontroller performs its function it either goes to an idle mode or to a sleep mode until it is summoned to perform another function. It is during the performance of a function, during operational mode, that a microcontroller requires more power to meet its operating voltage requirements. A microcontroller has a much lower power requirement during its idle or sleep mode than when it is performing a function. For example, a microcontroller which is installed

in a remote location to measure environmental data at some regular interval need not be in its operational mode at all times. The microcontroller may be in its sleep mode most of the time, except when it has to take the environmental data measurements. When measurements are required, the microcontroller wakes up, takes the measurements, logs the data and then goes to sleep. A microcontroller may be placed in a halt mode, where all activities are ceased and it has no power requirements. The only way to wake up the device is by reset or by device interrupt. For example, in a laptop keyboard, where power saving is required, the microcontroller is in halt mode until it detects a keystroke. When the microcontroller detects a keystroke, it wakes up, its mode changes from sleep mode to operation mode. Therefore an efficient method is needed to supply a microcontroller with power on demand and conserve power when the microcontroller is in sleep or idle mode.

Board space on a typical Printed Circuit Board (PCB) is limited, thus efforts should be made to optimize foot prints of the devices used and the number of pins for inter connection. The present generation of microcontrollers, requiring operating voltage of 4.5-5 volts, uses fewer

battery cells than prior generations in order to perform the same or a similar function. To supply the operating voltage requirements with a smaller number of dry cells, a separate power supply pump circuit is used to boost the relatively lower supplied voltage value to the required operating voltage value. A separate power supply pump circuit meets the demand of a microcontroller as far as the operating voltage is concerned, but such a power supply pump circuit has its own disadvantages. A separate power supply pump circuit requires additional space on the printed circuit board (PCB) and additional pins for interconnections. Space on the PCB for any device and pin connections are scarce commodities and efforts are always made to optimize such requirements. Minimizing the space requirements and reducing the number of pins for the interconnection of devices are needs to be addressed by designers and manufacturers.

To efficiently conserve power, a continuous interaction between a microcontroller and its power supply pump circuit is necessary. Such an interaction includes the microcontroller informing the power supply pump circuit of its power demands and the power supply pump circuit

supplying the required power when the power is needed.
Conventional power supply pump circuits communicate with
microcontroller and supply power to the microprocessor
based on the microprocessor's power demand. However, the
5 very process of communicating (e.g., driving input and
output pins) decreases the efficiency of power
conservation. Optimal operation of a microcontroller
requires efficient communication between the power supply
pump circuits and the microcontrollers.

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FOI b7D b7E b7F b7G b7H b7I b7J b7K b7L b7M b7N b7O b7P b7Q b7R b7S b7T b7U b7V b7W b7X b7Y b7Z

SUMMARY OF THE INVENTION

Therefore, a need exists to minimize the space required by the batteries supplying power to the microcontrollers. Also, a need exist to optimize the efficiency of the communication between the microcontroller and the power supply pump circuit in order to conserve the energy requirements of the microcontrollers. Another need exist to reduce the space required by the power supply pump circuit and the microcontroller on the PCB and to minimize the number of pins required to interconnect these devices. Still another need exist to maintain the microcontroller with minimum amount of power consumption during its sleep mode. The present invention provides a novel solution to these requirements

Accordingly, an embodiment of the present invention reduces the size of a power supply pump circuit by reducing a number of battery cells used to supply power to a device. Also, the efficiency of communication between a microcontroller and the power supply pump circuit is increased when both the power supply pump circuit and the microcontroller are integrated into one circuit and are housed in a single chip. Furthermore, integrating the power

supply pump circuit and the microcontroller causes a foot
print reduction on the PCB, thus satisfies the reduced
space requirements, and reduces the number of pins used for
interconnection. This invention further optimizes the
5 system's power consumption due to the dynamic interaction
between the two devices (e.g., the microcontroller and the
power supply pump circuit). The exchange of information
regarding the microcontroller's power requirements
optimizes power consumption by the microcontroller and
10 allows near zero power consumption when the microcontroller
is in a sleep mode.

These and other objects and advantages of the present
invention will no doubt become obvious to those of ordinary
15 skill in the art after having read the following detailed
description of the preferred embodiment which are
illustrated in the various drawing figures.

A method and a system for providing a power supply
20 pump circuit to supply power to a microcontroller. The
power supply pump is a part of the microcontroller and the
microcontroller dynamically interacts with the power supply
pump circuit. A battery initiates a supply of power

comprising a certain initial voltage to the power supply pump circuit. This initial voltage establishes a default operating voltage for the power supply pump. A voltage sensor senses the default operating voltage value of the power supply pump circuit. The voltage sensor is a programmable device, and dynamically interacts with the microcontroller to receive power requirements of the microcontroller. The voltage sensor updates the operating voltage value in accordance with the power requirements of the microcontroller. A drive enable receives the operating voltage value from the voltage sensor and maintains the operating voltage value. The power supply pump also includes a gate drive boost circuit. The gate drive boost circuit is configured to receive commands from the drive enable circuit and to fluctuate the operating voltage value according to the commands received from the drive enable circuit. The drive enable circuit regulates the fluctuation of the operating voltage value in accordance with changes in the power requirements of the microcontroller. A passive precharge circuit drives the power supply pump before the voltage sensor and the drive enable begin their normal operation.

A method and a system for supplying power to a microcontroller with a single cell battery are disclosed. One embodiment of the present invention discloses the incorporation of a power supply pump circuit with the microcontroller and their dynamic interaction. The microcontroller sends its power requirements to the power supply pump circuit, and in response, the power supply pump circuit controls the operating voltage with optimal efficiency. The dynamic update of power supply pump circuit results in an efficient use of the power supply pump circuit, and consequently, a reduction of the number of batteries to only a single cell battery. Incorporation of the microcontroller and power supply pump circuit onto a single chip reduces the number of pins required for connectivity as well as the space required on the printed circuit board.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and form a part of this specification, illustrate embodiment of the invention and, together with the description, serve to explain the principles of the invention:

Figure 1 is a block diagram of a typical power supply pump circuit and its interaction with a microcontroller.

Figure 2 is exemplary incorporation of a power supply pump circuit and a microcontroller.

Figure 3 is a flowchart of the steps in a process of initiating power supply pump operation and supplying the power requirements of a microcontroller.

Figure 4 is a flowchart of the steps in a process of a dynamic interaction the power supply pump circuit and a microcontroller.

Figure 5 is a flowchart of the steps in a process of initiating power supply pump operation with a single cell.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made in detail to preferred embodiment of the invention, a power supply pump circuit for a microcontroller circuit, examples of which are illustrated in the accompanying drawings. While the invention will be described in conjunction with the preferred embodiments, it will be understood that they are not intended to limit the invention to these embodiments. On the contrary, the invention is intended to cover alternatives, modifications, and equivalents, which may be included within the spirit and scope of the invention as defined by the appended claims. Furthermore, in the following detailed description of the present invention, numerous specified details are set forth in order to provide a thorough understanding of the present invention. However, it will be obvious to one of ordinary skill in the art that the present invention may be practiced without these specific details. In other instances, well known methods, and circuits have not been described in detail as not to unnecessarily obscure aspects of the present invention.

Figure 1 is a block diagram of system 100 which includes power supply pump system 101 incorporated with microcontroller 180 on a single Integrated Circuit (IC). As depicted in Figure 1, system 101 includes a power supply pump circuit including a ring oscillator 110, a passive precharge circuit 120, a drive enable 130, a gate drive boost 140, and a voltage sensor 150. Battery circuit 199 includes a single cell battery 196, an inductor 195, a capacitor 198 and a diode 190. The components 110-180 are integrated "on chip" into a single integrated circuit. The components 190-198 are "off chip".

Ring oscillator 110 generates the clock signals used by logic components of system 101. Ring oscillator 110 starts operating when V_{cc} 197 attains some nominal initial voltage value, in this embodiment, of approximately 1 Volt. It is appreciated that the Ring oscillator 110 may operate during the sleep mode of microcontroller 180.

Passive precharge 120 causes the single cell battery 196 to operate for a short period of time, until V_{cc} 197 reaches an initial minimum voltage for effective gate drive (e.g., approximately 1 Volt). This voltage value causes

interaction between all components of the power supply pump circuit 101 and the microcontroller 180, this voltage is considered as the initial operating voltage. The initial operating voltage is achieved when passive precharge 120 shorts diode 190 causing battery 196's current to flow through inductor 195 and charging capacitor 198. The current from battery 196, during a short period of time, a transitory period, charges capacitor 198 to the level that it acts as a mini battery and can run ring oscillator 110 long enough to have gate drive boost 140 to start its boosting operation. Passive precharge 120 takes itself out of the circuit as soon as V_{cc} 197 is boosted to the initial operating voltage value, in this embodiment 1 Volt.

Voltage sensor 150 is a programmable device and selects the operating voltage for the power supply pump circuit. Voltage sensor 150 senses V_{cc} 197 voltage after the transitory period and considers that voltage as the initial operating voltage. At this voltage level, voltage sensor 150 is enabled to interact with drive enable 130. It is appreciated that V_{cc} 197 voltage is common to all devices of system 101 and battery circuit 199. When voltage sensor 150 senses the initial operating voltage of 1 volt, Power

On Reset Circuit (POR), which is a circuit inside voltage sensor 150 signals the operating status of the microcontroller 180 to voltage sensor 150. This circuit is a state dependent circuit that notifies voltage sensor 150 whether the microcontroller 180 is waking up or is being initialized.

There is no interaction between voltage sensor circuit 150 and microcontroller 180 at voltages below the minimum operating voltage of microcontroller 180. However, interaction between power supply pump circuit 150 and microcontroller 180 commences immediately after the minimum operating voltage of microcontroller 180 is reached. At this voltage level microcontroller 180 configures voltage sensor 150 of its desired parameters including its minimum operating voltage and its future voltage requirements. On the other hand, POR has also notified voltage sensor circuit 150 of microcontroller 180's operating status.

If microcontroller 180 is being initialized, voltage sensor 150 request an increase in initial operating voltage from drive enable 130. Drive enable 130 commands gate drive boost 140 to start the boosting operation and to continue

the boosting operation until drive enable 130 sends a subsequent command to stop the boosting operation. Drive enable 130 sends a command to gate drive boost circuit 140 to stop boosting operation when drive enable 130 is notified by voltage sensor 150 that the minimum operating voltage of the microcontroller 180 has been reached. Microcontroller 180 starts its dynamic interaction with voltage sensor circuit 150 and configures voltage sensor 150 to its desired parameters.

From this point on voltage sensor 150 notifies drive enable 130 of microprocessor 180's voltage requirements and drive enable 130 commands gate drive boost 140 to maintain the required voltage. Gate drive boost 140 receives the voltage requirements from drive enable 130 and fluctuates the voltage by changing the duty cycle of transistor 160 as required. Gate drive boost 140 functions by turning transistor 160 on or off. When transistor 160 is off the current flows into diode 190 and capacitor 198. Capacitor 198 integrates current into voltage and voltage starts to ramp up. The ramp rate is controlled by the duty cycle of transistor 160, and is the ratio of transistor 160's off time to on time

For example, during a start up, Passive Precharge circuit 120 sets V_{cc} 197 equal to 1 Volt. V_{cc} 197 voltage of 1 Volt is common to all devices included in power supply system 101. When the voltage reaches the minimum operating voltage of microprocessor 180, dynamic interaction between voltage sensor 150 and microcontroller 180 begins and microcontroller 180 configures voltage sensor 150 with its voltage requirements.

Gate drive boost 140 receives operating voltage requirements from drive enable 130. Gate drive boost 140 increases the operating voltage by controlling transistor 160. Gate drive boost functions by turning transistor 160 on or off. When transistor 160 is off the current flows into diode 190 and capacitor 198. Capacitor 198 integrates current into voltage and voltage starts to ramp up. The ramp rate is controlled by the duty cycle of transistor 160, and is the ratio of transistor 160's off time to on time.

In one embodiment of the present invention, the minimum operating voltage of microcontroller 180 is 2.7

- but diode 190 could be an off chip device or in other embodiments could be eliminated.

5 Incorporating power supply pump circuit 101 and microcontroller 180 into a single chip improves communication between the two devices (e.g., microcontroller 180 and power supply pump circuit 100). Dynamic interaction between these devices (e.g., ring oscillator 110, drive enable 130, gate drive boost 140, voltage sensor 150) is a major factor in optimizing power consumption. Incorporating these two devices (e.g., ring oscillator 110, drive enable 130, gate drive boost 140, voltage sensor 150) into a single integrated circuit 210 of Figure 2 will result in a more efficient communication.

10 Another advantage of incorporating power supply pump circuit 101 and microcontroller 180 is reduction in the footprint of single integrated circuit 210 of Figure 2 on the printed circuit board.

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20 The present invention provides a single integrated circuit 210 of Figure 2 to take the place of a separate power supply pump circuit 101 and microcontroller 180. The present invention provides diode 190 to be integrated

inside single integrated circuit 210 of Figure 2, outside
as depicted in Figure 2 or could be completely left out.
Leaving diode 190 outside single integrated circuit 210 of
Figure 2 improves the performance of the circuit and is
5 also more cost effective, because a higher quality and a
less expensive diode could be used. Furthermore, a single
discrete power supply pump circuit 101 has to have a
voltage sensor which in and itself consume a fair amount of
power. Integration of these devices into a single
10 integrated circuit 210 of Figure 2 eliminates such an
unnecessary use of power.

Another advantage of this embodiment of the present
invention is that V_{cc} 197 can provide power to devices on
15 the printed circuit board external to system 100.

Figure 3 is a flowchart of the steps of a process 300
of initiating power supply pump operation and dynamic
response to the power requirements of a microcontroller.

20 In step 310 of Figure 3, the process 300 explains
generation of an initial operating voltage of a power

supply pump circuit by using a passive precharge circuit
for a power supply pump circuit.

In step 320 of Figure 3, the process 300 shows
boosting the initial operating voltage to a minimum
operating voltage using a voltage sensor included in the
power supply pump circuit, the voltage sensor begins the
boosting upon receiving the initial operating voltage.

In step 330 of Figure 3, the system 300 provides the
minimum operating voltage of the power supply to a
microcontroller.

In step 340 of Figure 3, this step of process 300
shows the microcontroller commanding the voltage sensor to
maintain the minimum operating voltage or to increase the
minimum operating voltage to a higher operating voltage.

Figure 4 is a flowchart of the steps of a process 400
of initiating the power supply pump operation and a dynamic
response to the power requirements of a microcontroller
thus increasing the efficiency of the system.

In step 410 of Figure 4, the power supply pump circuit and the microcontroller are integrated into a single integrated circuit.

5 In step 420 of Figure 3, the power supply pump circuit dynamically interacts with the microcontroller.

10 In step 430 of Figure 4, the power supply pump circuit receives a voltage requirement of the microcontroller and efficiently provides the voltage requirements to the microcontroller.

15 In step 440 of Figure 4, the power consumption of the microcontroller is optimized when the power supply pump circuit provides voltage to the microcontroller when the microcontroller is in operation mode.

20 Figure 5 is a flowchart of the steps of a process 500 of initiating a power supply pump operation and a dynamic response to the power requirements of a microcontroller, thus optimizing power consumption.

- In step 510 of Figure 5, initial operating voltage is generated by connecting a passive precharge circuit to a battery circuit.

5 In step 520 of Figure 5, the initial operation of a drive enable circuit, a voltage sensor circuit, a ring oscillator circuit, and a gate drive boost circuit is initiated at the initial operating voltage.

10 In step 530 of Figure 5, the operating voltage is boosted to a minimum operating voltage of microcontroller.

15 In step 540 of Figure 5, system 500 shows monitoring the microcontroller's minimum operating voltage using a voltage sensor device and increasing the minimum operating voltage to a voltage level demanded by the microcontroller.

20 The foregoing descriptions of specific embodiments of the present invention have been presented for purpose of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise form disclosed, and obviously many modifications and variations are possible in light of the above teaching. The

embodiments were chosen and described in order to best explain the principles of the invention and its practical application, to thereby enable others skilled in the art to best utilize the invention and various embodiments with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the Claims appended hereto and their equivalents.

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